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Stapedius Reflex Measurements During Surgery for Cochlear Implantation in Children

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Summary: Electrically evoked stapedius reflex measurements were obtained in 19 children during surgery for cochlear implantation. They all received the Nucleus device. Stapedius reflexes could be elicited in all the children with congenital deafness but not in all the children with an etiology of meningitis. The intraoperative stapedius reflex thresholds were compared with postoperative values obtained after fitting of the speech processor and with the children's long-term behavioral most comfortable levels (C-levels). The intraoperative reflex thresholds were considerably higher than the postoperative reflex thresholds (44 "stimulus level steps" on the average), which could in part be ascribed to the influence of anesthetics used during surgery. It was concluded that, especially in children with an etiology of meningitis, the intraoperative stapedius reflex threshold (even after corrections for the concentration of the volatile anesthetics used) was a weak predictor of the C-level. **Key Words:** Intraoperative measurements—Cochlear implantation—Stapedius reflex.
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An essential part of the successful application of a cochlear implant is to adjust the stimulation levels to the patient's dynamic range. This can be a problem, especially in young children. To overcome this, several authors have advocated the use of objective threshold measurements during surgery, such as electrically evoked auditory brain stem response (EABR) thresholds and electrically evoked stapedius reflex (ESR) thresholds (1–8). It has been suggested that EABR and ESR thresholds can be used to predict the behavioral threshold and the most comfortable level, respectively (3–8). However, postoperative measurements showed that EABR thresholds were not specifically related to behavioral thresholds; in several patients, they were even closer to the most comfortable levels (2,3,5,6). Although ESR thresholds were found to be related to the most comfortable levels, they overestimated these levels in several patients (4,5,9). To date, both techniques (EABR and ESR measurement) are in use, but there are no decisive arguments in favor of one or the other. A technical restriction of the EABR measurement is that it is much more susceptible to noise and electrical artifacts than the ESR measurement. Furthermore, the pulse repetition rate for EABR recordings (typically 15–40 pps) is much lower than the rate at which the implant works. This complicates the prediction of behavioral measures from EABR measures. For ESR measurements, there are no constraints in this respect. On the other hand, ESR measurement requires normal middle ear function. In a previous study, we compared the outcomes of the two techniques in the same patients (5). There was less deviation of the postoperatively determined ESR thresholds (better grouped in the patient's dynamic range) than the EABR thresholds. Thus, there seem to be some arguments in favor of the ESR measurement.

The value of intraoperative measurement of ESR and EABR thresholds for device fitting has been studied by several groups (3,6–8,10,11). These studies showed that if certain precautions were taken and/or corrections were made the outcomes could be considered as suitable for device fitting. However, the error of estimation was found to be significant in several cases. [It should be noted that the intraoperative EABR measurement has been advocated for another main purpose, namely for selection of the ear of implantation (12).] A specific problem with intraoperative ESR measurement is that anesthetic agents may weaken the stapedius reflex (10,13–16). The effects of most agents are not well described except for muscle relaxants and volatile gaseous agents (10,13,15).

In the present study, we evaluated the ESR thresholds of 19 children determined during cochlear implant surgery. The following issues were examined in retro-

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spect: the effect of the etiology of deafness, the effects of the anesthetic agents used during surgery (muscle relaxants, volatile gaseous agents), and the relation between the ESR thresholds and device-fitting parameters. The effects of other anesthetic drugs administered intravenously were not studied systematically, because a great diversity of agents and combinations was applied by the anesthetists to achieve optimal anesthesia.

The intraoperative ESR measurement was performed after insertion of the electrode array just before closing the middle ear cavity, while the administration of relaxants was discontinued. In several children, the measurement was repeated at the end of surgery just before the wound was dressed. At this time, the child was breathing on his/her own and muscle relaxants had not been administered for at least 45 min. This additional measurement was introduced to see whether there was any improvement at the end of surgery owing to further wash-out of muscle relaxants or recovery from deep anesthesia. Furthermore, ESR thresholds were obtained after the fitting of the speech processor to see whether or not the intraoperative values were close to the real ESR thresholds (the so-called postfitting ESR thresholds). Finally, each child's intraoperative ESR thresholds were compared to their (long-term) most comfortable levels.

MATERIALS AND METHODS

Subjects

ESR measurements were performed on 25 children during cochlear implant surgery. They all received the Nucleus 22-electrode cochlear implant. In four of the children, the electrode array could only be inserted partially; the results of these children were excluded. In two other children, ESR measurement was discontinued because of the absence of the stapedius tendon in one child and thick mucosa around the stapes in the other. Therefore, the data of 19 children were available for evaluation.

Some biographic data are presented in Table 1. Six of the children had congenital deafness. The cause of deafness in the others was meningitis. The age at implantation was 3.9–12.3 years. During surgery, minor ossification in the scala tympani was found in six of the children, which needed some drilling. The integrity of all the implants was checked according to the procedure described by Mens et al. (17). All the children had been using their cochlear implant on a daily basis for at least 10 months. Word identification testing revealed scores that were significantly above chance in all the 19 children.

Procedure

To elicit the ESR, biphasic pulses with variable width ("stimulus level") with a repetition rate of 250 pps were presented for 1 s. The "common ground" stimulation mode was used (as it was for device fitting). The stimuli were generated by the DPS software and presented via a speech processor linked to the DPI interface.

As volatile anesthetics, Halothane was used in 13 children and Isoflurane in six children, depending on the anesthetist's preference.

After insertion of the electrode array, before closing of the middle ear cavity, the transmitter coil was placed in a sterile bag and positioned over the receiver. Contractions of the stapedius muscle were monitored by means of the operation microscope and television screen. Observations were made during stimulation; thereto, the presence of a stimulus was indicated by an acoustic signal. Prior to testing, the administration of muscle relaxants was discontinued and muscle activity was normal according to neuromuscular monitoring of limb muscles (16).

Stimulation was started at a "stimulus level" of 100 and increased with steps of 10 levels up to level 230, if necessary. When a response was found, the stimulus was increased once more by 10 levels to verify the presence of a stapedius reflex. Afterwards, the level was decreased by 20, and the measurement was repeated with steps of five levels. Electrodes 1, 5, 10, 15, 20, and, in some children, also 22 were tested.

In nine of the patients, the stapedius reflex measurement was repeated at the end of surgery. This time, the stapedius reflex was determined at maximum compliance in the contralateral ear using a clinical impedance meter (Amplaid 702). The stimulation procedure was identical to that used for visual determination of the reflex. At least 3 months after the speech processor had been fitted, ESR measurements were repeated on 13 of the children (the so-called postfitting ESR). The remaining six children did not participate because of various reasons. The measurement set-up and procedure were identical to those used at the end of surgery, except that the initial stimulation level was the child's behavioral threshold, and step size below the most comfortable level (or C-level) was five levels and above the C-level was two levels. The maximum stimulation level was the child's uncomfortable loudness level.

To study the value of intraoperative ESR thresholds for the prediction of C-levels, the most recent fitting results were used, obtained at least 6 months after the initial speech processor fitting. According to the audiologist, the C-levels could be considered reliable in all the 19 children.

TABLE 1. *Mean age at implantation (AaI) and mean duration of deafness (DoD) of the children subdivided according to etiology and the elicitability of the stapedius reflex (ESR) during surgery*[a]

Etiology	Intraoperative ESR	n	AaI (years)	DoD (years)
Congenital	Present	6	8.3 (2.7)	8.3 (2.7)
	Absent	0		
Meningitis	Present	9	7.2 (2.1)	5.0 (2.1)
	Absent	4	7.9 (3.3)	4.8 (1.8)

[a]SDs are indicated between brackets.

RESULTS

Incidence of electrically evoked stapedius reflex

In the majority of children, ESR thresholds could be established visually. Figure 1 shows the incidence of intraoperative ESR versus the electrode number for the children with congenital deafness and for those children whose cause of deafness was meningitis. A clear difference was observed between both groups. The poor result of the meningitis group compared to the congenital group could not be ascribed to the age at implantation or the interval between the onset of deafness and implantation as these were either statistically indistin-

guishable or to the advantage of the children whose cause of deafness was meningitis (Table 1).

Comparison of the visually established ESR thresholds and the ESR thresholds obtained at the end of surgery showed that a reflex could be elicited on both occasions in five of the nine patients tested and could not be elicited on either occasion in three patients. In one patient, a reflex could be established visually (although only at the extremes of the electrode array, electrodes 1 and 20), but not at the end of surgery. The average ESR threshold established visually was 12 levels below that established at the end of surgery (range, 30 to -5). This means that there was no improvement in the ESR thresholds at the end of surgery.

Postfitting ESR thresholds were found in nine out of the 13 children tested (Table 2). In the other four children, it was not possible to evoke a stapedius reflex up to the highest stimulus level that the child could tolerate. Again, the results of the meningitis group were poorer than those of the congenital group. In two patients whose cause of deafness was meningitis, no reflex could be elicited during surgery, but a reflex could be elicited later on. However, in these two children, a postfitting ESR was found at one and two electrodes, respectively, close to the children's uncomfortable loudness level. Furthermore, the ESR was of the diphasic, on-off type.

TABLE 2. *Comparison between the intraoperative ESR and postfitting ESR in 13 children*

		Postfitting ESR	
Etiology	Intraoperative ESR	Present	Absent
Congenital	Present	5	0
	Absent	0	0
Meningitis	Present	2	2
	Absent	2	2

Effect of volatile anesthetic agents

Comparison of the intraoperative and postfitting ESR threshold values showed that, on average, the intraoperative ESR threshold was 44 levels higher (SD, 31; range, 2–100 levels) in the children who displayed an ESR. This discrepancy can partly be ascribed to anesthesiological factors, as illustrated in Fig. 2. This figure shows the relation between the expiratory concentration of Halothane and the ESR threshold in an individual child. Initially, the Halothane concentration was 0.6% (volume %; measurement A); then, it was increased to 2% (measurement B) and finally decreased again to 0.6% (measurement C). ESR measurements were performed under all three conditions with a 5-min interval between the Halothane adjustment and the ESR measurements. A significant increase in the ESR thresholds was seen after the increase in concentration, with recovery after the Halothane concentration had decreased. The ESR threshold increased by approximately four levels per 0.1% Halothane between measurements A and B. Next, the relation between the individual intraoperative ESR thresholds and the percentage of Halothane used was determined in all the children who received Halothane. As an example, Fig. 3 shows this relation for electrode 1. The results of nine children are shown because ESR thresholds were obtained from only nine out of the 13 children who received Halothane during the surgery. The correlation between the ESR threshold and the percentage of Halothane was 0.85, which was significant at the 1% level. At the other electrode positions, similar results were obtained. The dotted line represents the four-level increase per 0.1% Halothane found in the former experiment (Fig. 2). The slope of this line fits reasonably well with the increase in the ESR threshold with increasing Halothane concentration. Therefore, as a first order approximation, the intraoperative ESR thresholds were corrected for the effect of Halothane by lowering them by a factor of four times the concentration of Halothane expressed in multiples of 0.1%. The average difference between the intraoperative ESR thresholds and the postfitting ESR thresholds, which was 44 levels before correction, was 18 levels (SD, 23; range, -18 to 55) after correction. This indicated that correction was beneficial.

Next, the corrected intraoperative ESR thresholds were compared to the corresponding C-levels. On the average, the ESR thresholds were 13 levels above the C-levels (SD, 38; 32 observations in nine children). Without the correction, the discrepancy was 46 levels. In eight out of the nine children, the corrected ESR thresholds were close to or above the C-levels. In one child, the ESR thresholds were found at levels clearly below the C-levels. The ESR results in the six children who received Isoflurane are also presented in Fig. 3. The

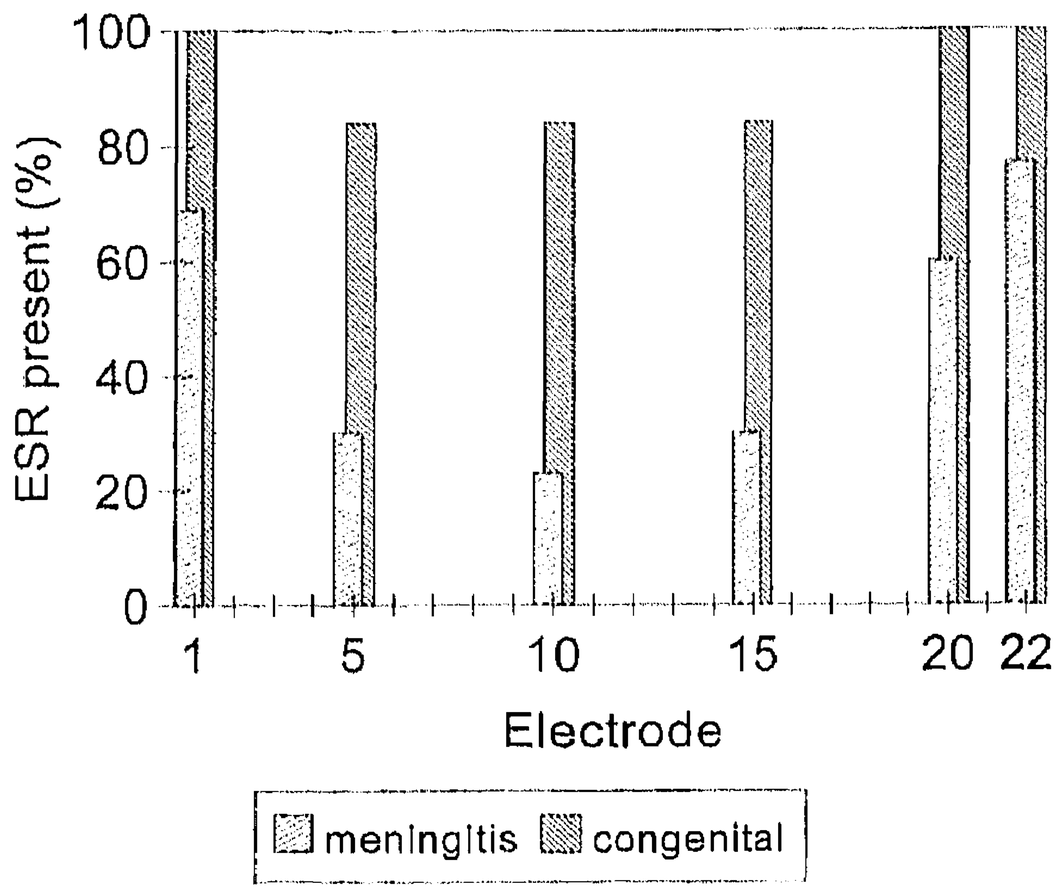

FIG. 1. The incidence of electrically evoked stapedius reflex (ESR) during cochlear implant surgery as a function of electrode number. The results of the congenital group (n = 6) and meningitis group (n = 13) are presented separately.

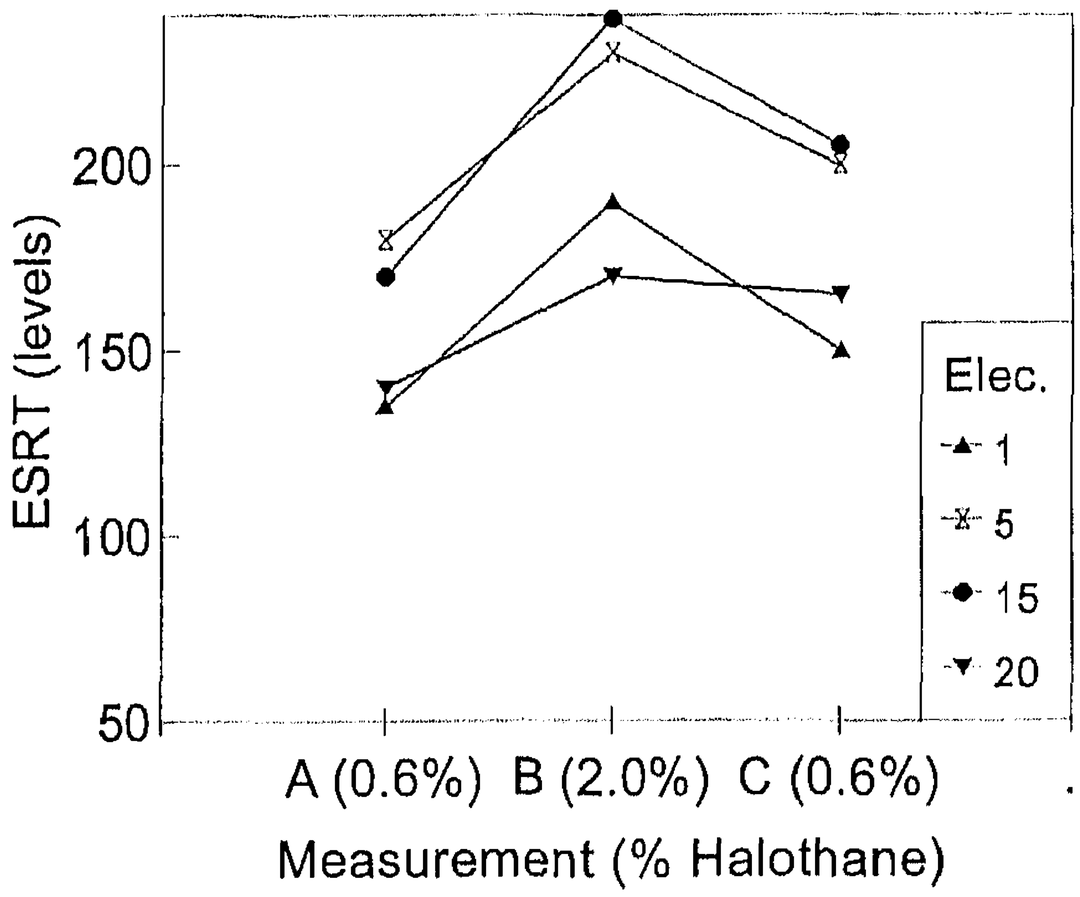

FIG. 2. Intraoperative stapedius reflex thresholds (ESRT) from a child in whom the concentration of Halothane was changed during the measurements from 0.6% (measurement A) to 2.0% (B), and 0.6% (C). Results of different electrodes are presented.

pattern was similar to that for Halothane, but the correlation was not significant. Therefore, it was not considered feasible to correct these ESR threshold values, as was done for Halothane.

DISCUSSION

During surgery, ESR thresholds were established twice in a number of children: once with, in principle, less objective visual determination and once, at the end of surgery, with the middle ear impedance measurement. Comparison of the results showed that there was no improvement in the ESR thresholds at the end of surgery, which means, firstly, that the visual determination of the stapedius reflex was adequate and, secondly, that (further) wash-out of muscle relaxants or recovery from deep anesthesia at the end of surgery did not improve the reflex thresholds.

An ESR could be established visually in most of the children, but the response of some of them with an etiology of meningitis was poor. Mason et al. (7) and Battmer et al. (8) reported that a stapedius reflex could be elicited intraoperatively in all of their cases, but not at all the electrodes; in the present study, this was only found in the children with a congenital etiology. Mason et al. (7) reported that most of their "no response" measurements concerned electrodes in the center of the electrode array; the present observations were in agreement with this. No intraoperative ESR could be elicited in 30% of the children whose cause of deafness was meningitis. Postfitting ESRs could not be obtained in as many as 50%. These differences between the congenital group and meningitis group could not be ascribed to age at implantation or duration of deafness. Poor elicitability of the stapedius reflex in the meningitis cases is in accordance with the results reported by Spivak et al. (9), who found that ESR thresholds could be determined postoperatively only in a minority of children whose etiology was meningitis, but in the majority with a congenital etiology. This suggests that the reflex arc may be compromised in the children whose cause of deafness is meningitis. Additional support for this assumption is the intraoperative measurement of the compound action potential reported by Gantz et al. (18). They found that the performance of children with congenital deafness was better than that of the children whose cause of deafness was meningitis. They suggested that the congenital deaf children presumably had better eighth nerve survival.

After surgery, reflex thresholds were found at lower levels than during surgery, even after correction had been applied for the effect of Halothane. The remaining discrepancy of 18 levels may be ascribed to the influence of other anesthetic agents or improved sensitivity of the neural system to stimulation. In their study on the influence of anesthetic agents on the ESR, Gnadeberg et al. (10) also compared intra- and postoperative ESR thresholds. At best, they found an average discrepancy of 10 levels; this is in fair agreement with the present results. Brown et al. (6) reported that electrically evoked ABR thresholds obtained postdevice fitting were on average 20 levels lower than the intraoperative values. The present discrepancy of 18 levels compares well with their value. As brain stem responses are largely unaffected by the most commonly used anesthetic agents (19), improved sensitivity of the auditory neural system probably caused the discrepancy, not the anesthetics.

On average, the corrected ESR thresholds were 13 levels above the C-levels, but the SD was high. This

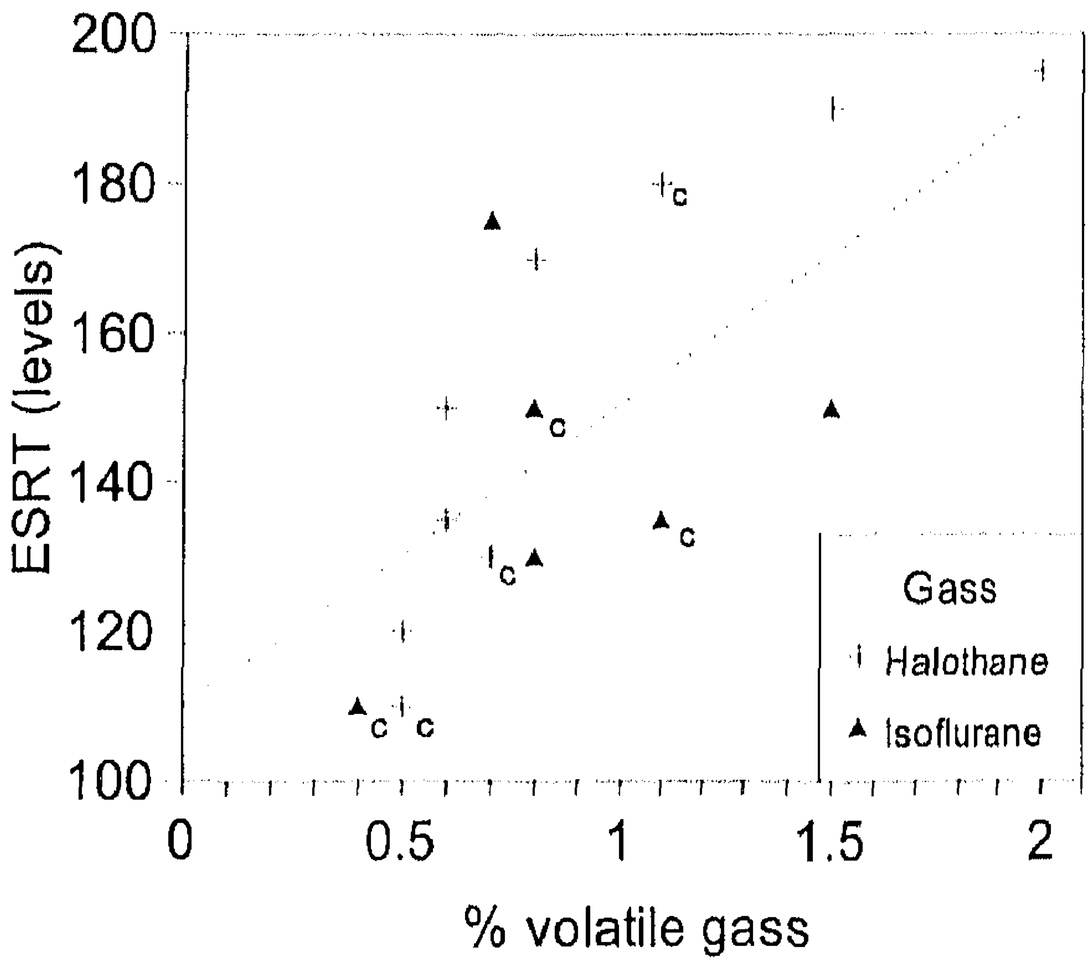

FIG. 3. Individual Intraoperative stapedius reflex thresholds (ESRT) of electrode 1 as a function of the concentration of Halothane (n = 9) or Isoflurane (n = 6) administered during surgery. The subscript c refers to results of children whose onset of deafness was congenital.

means that the relation between the two measures was poor. A similar conclusion can be drawn from the results presented by Mason et al. (7). Diphasic reflex waveforms were found postdevice fitting in two children in the meningitis group. It has been reported that diphasic stapedius reflexes are fairly common in the early stages of otosclerosis (20). During surgery, there was some ossification in the scala tympani of both children. It is suggested that, in these two cases, the stapes might have been less mobile than normal owing to the spread of ossification into the scala vestibuli. The most common location for bone growth in meningitis is the basal turn region of the scala tympani (21), but the scala vestibuli may also be involved in some cases (22). Decreased mobility of the stapes might have been the reason why, during surgery, no ESR was observed in these two cases. In four other children with ossifications, normal stapedius reflex waveforms were found, which may be ascribed to ossification restricted to the scala tympani.

To conclude, if no ESR is observed during surgery, which occurs in a number of cases with an etiology of meningitis, no conclusions can be drawn. If an ESR is found, the results suggest that the ESR thresholds can only be considered as weak predictors of the C-levels, especially if meningitis was the cause of deafness. EABR measurements might be a better choice in these patients.

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